BeAGLE: eRD17

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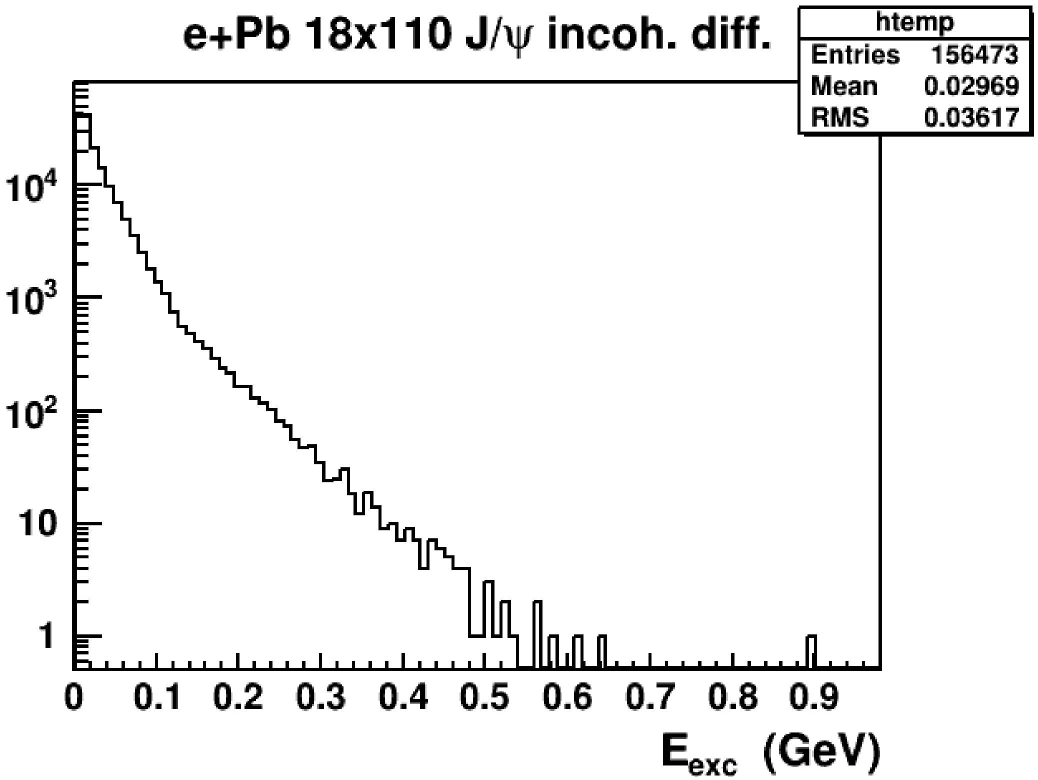
26-July-2018

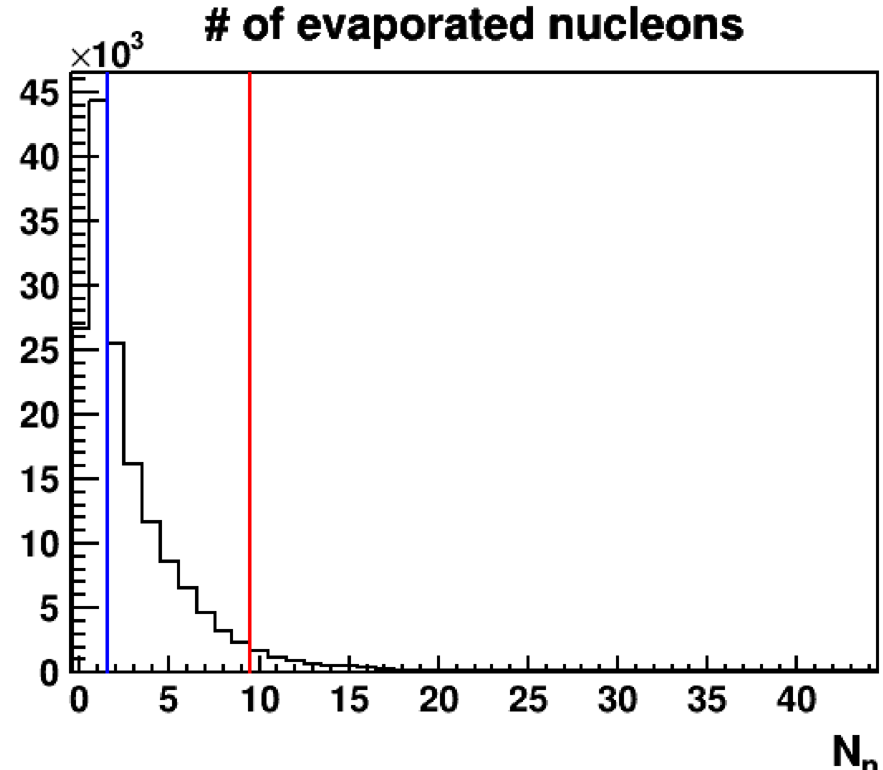
HMS Beagle from wikipedia...

Following up from last meeting...

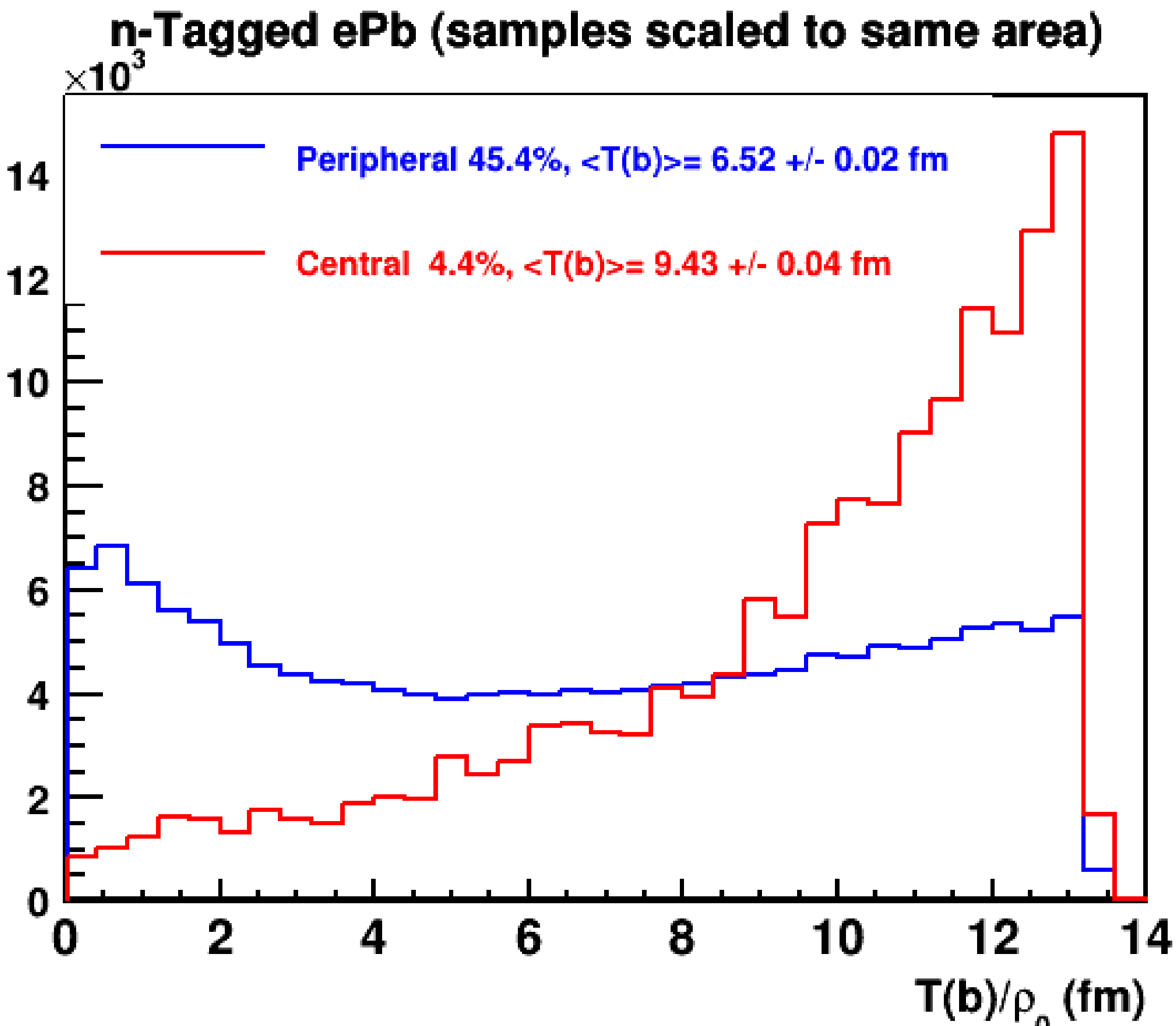
- Evaporation neutrons CAN tag collision geometry for incoherent diffractive e+A
  - Committee requested more details.
- Evaporation neutrons appear to be insufficient to tag coherent vs. incoherent diffraction
  - Look at other options...
- Ongoing effort to include RAPGAP & tune to E665 μ+Xe Streamer Chamber data.
  - Validate BeAGLE! Proposed for FY2018-FY2019

Incoherent Diffraction distributions



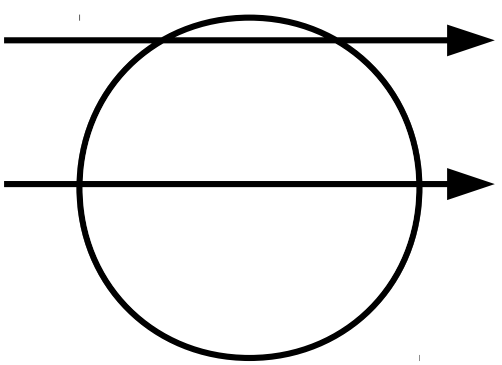


Centrality for incoherent diffraction

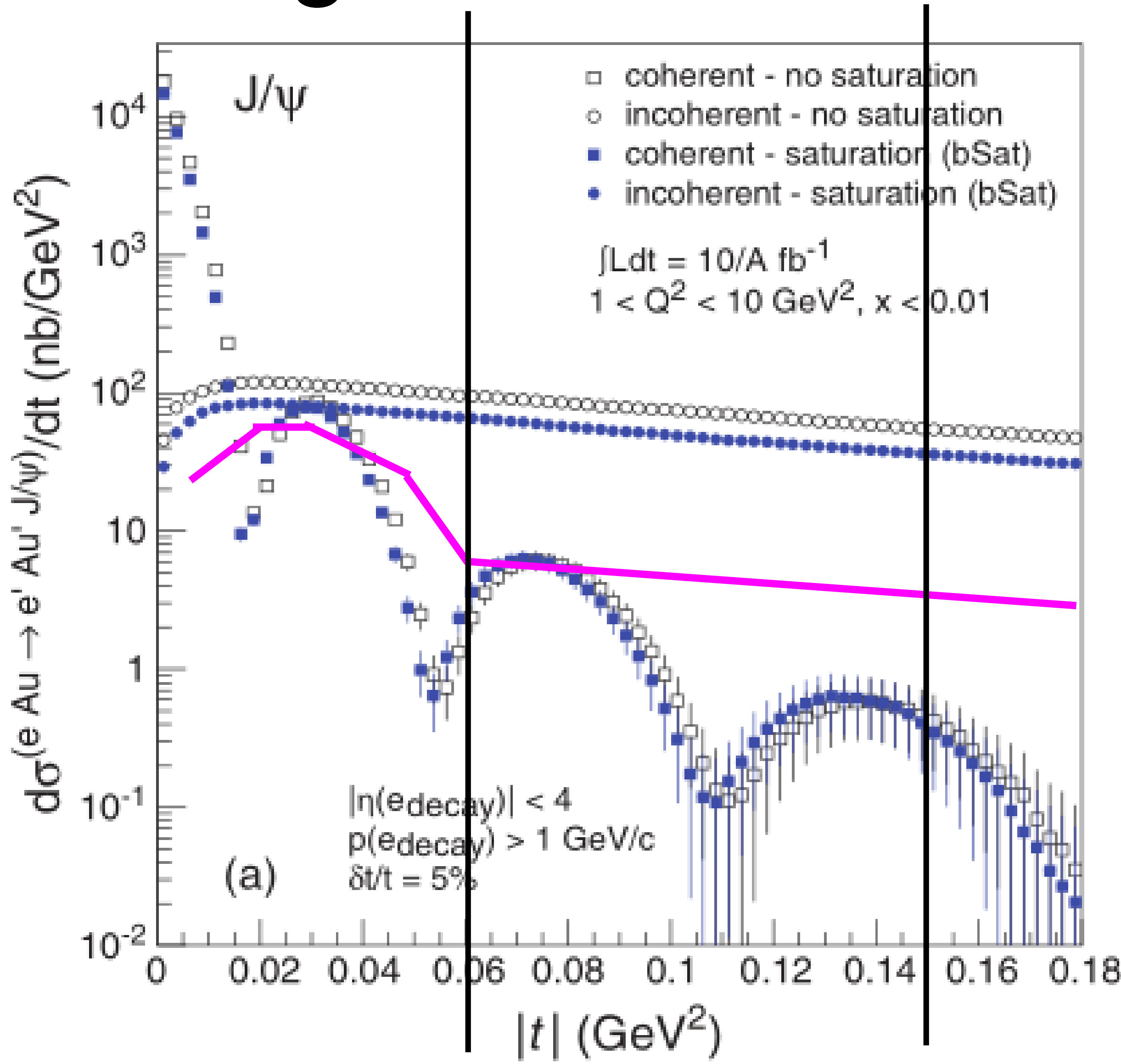


18x110 GeV e+Pb → e' + J/ψ + X

Effective thickness seen by γ* (in fm)

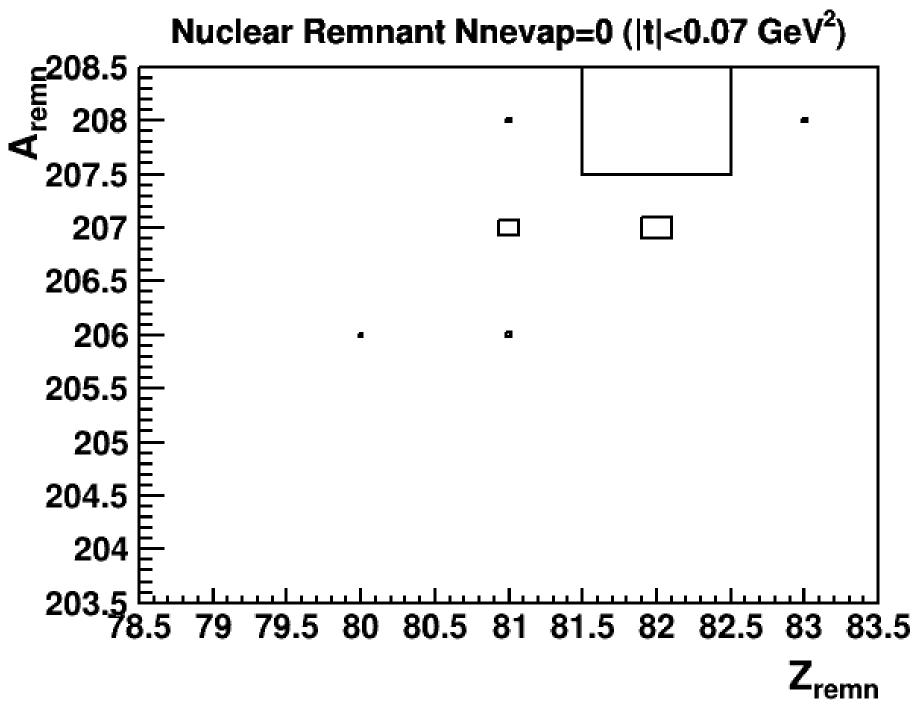


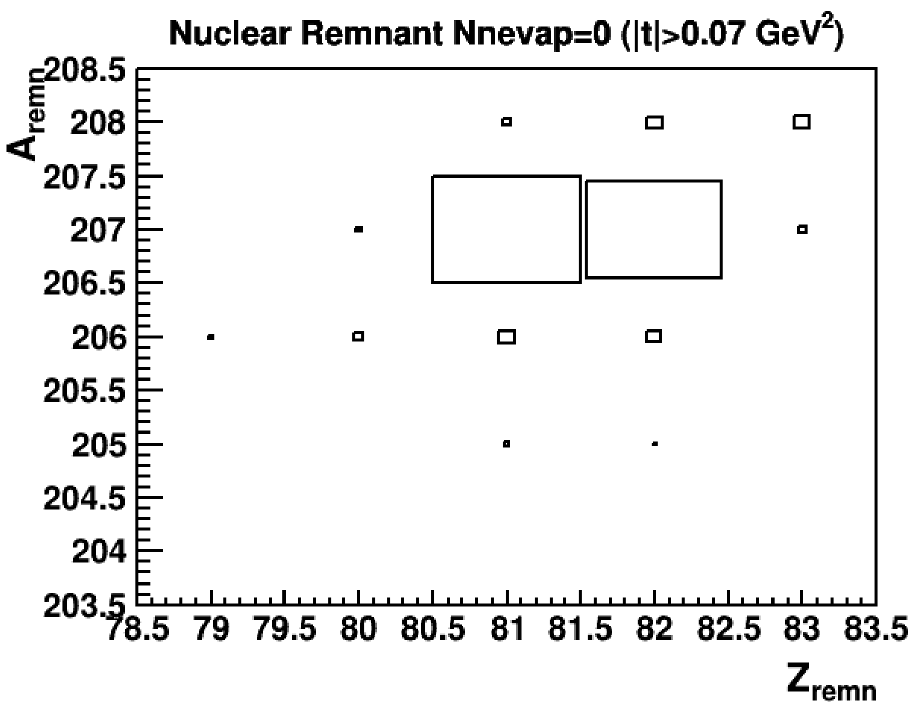
ZDC n background veto inadequate



Incoherent (bSat) after:
Nnevap cut

Remnants for Nnevap=0





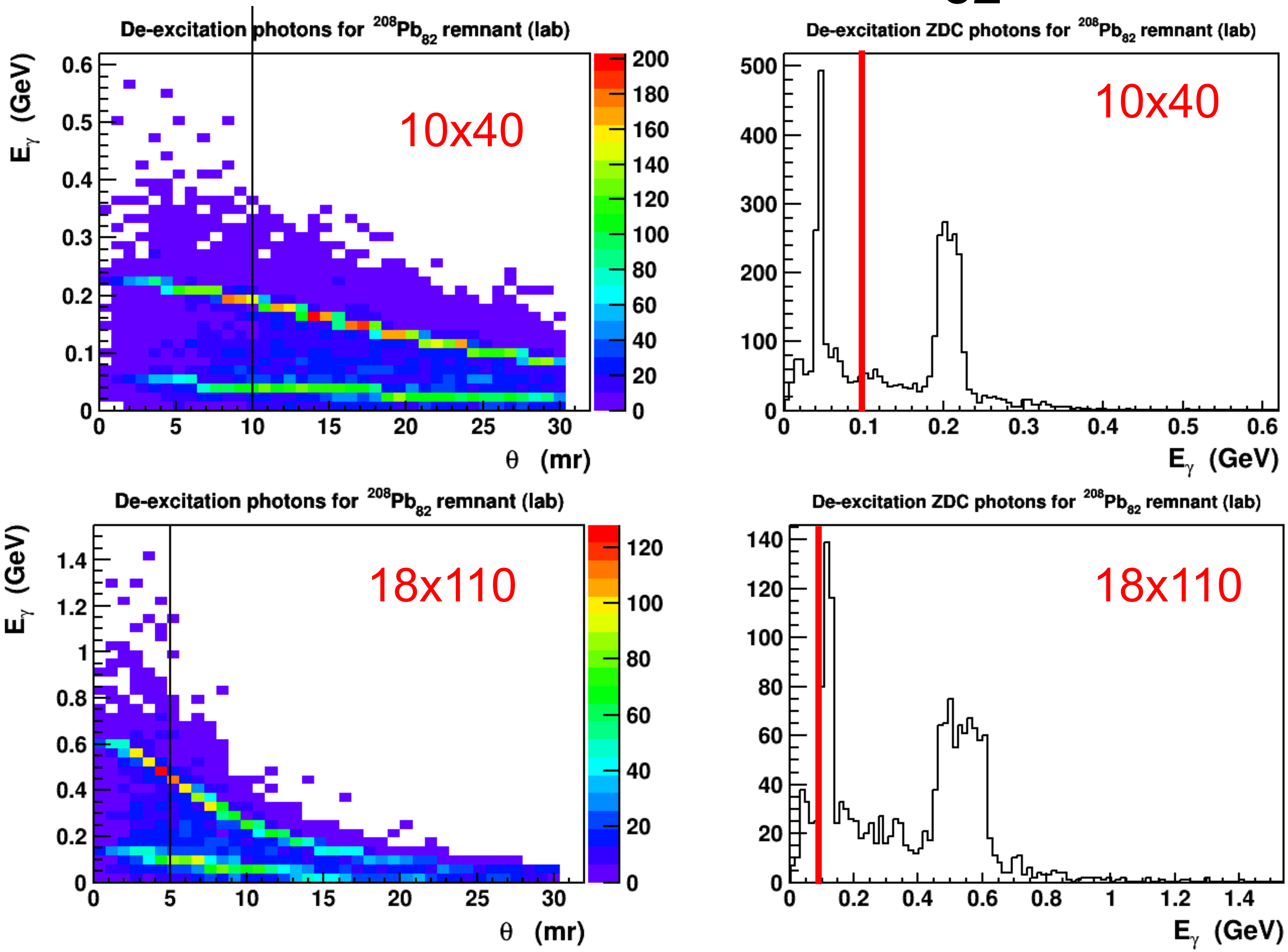
Low |t|: The struck nucleon can be recaptured.

$\gamma^* + {}^{208}Pb_{82} \rightarrow \psi + {}^{208}Pb_{82} + \gamma + \gamma + \gamma \ldots$

High |t|: The struck nucleon escapes:

$p + {}^{207}Tl_{81}$ or $n + {}^{207}Pb_{82}$

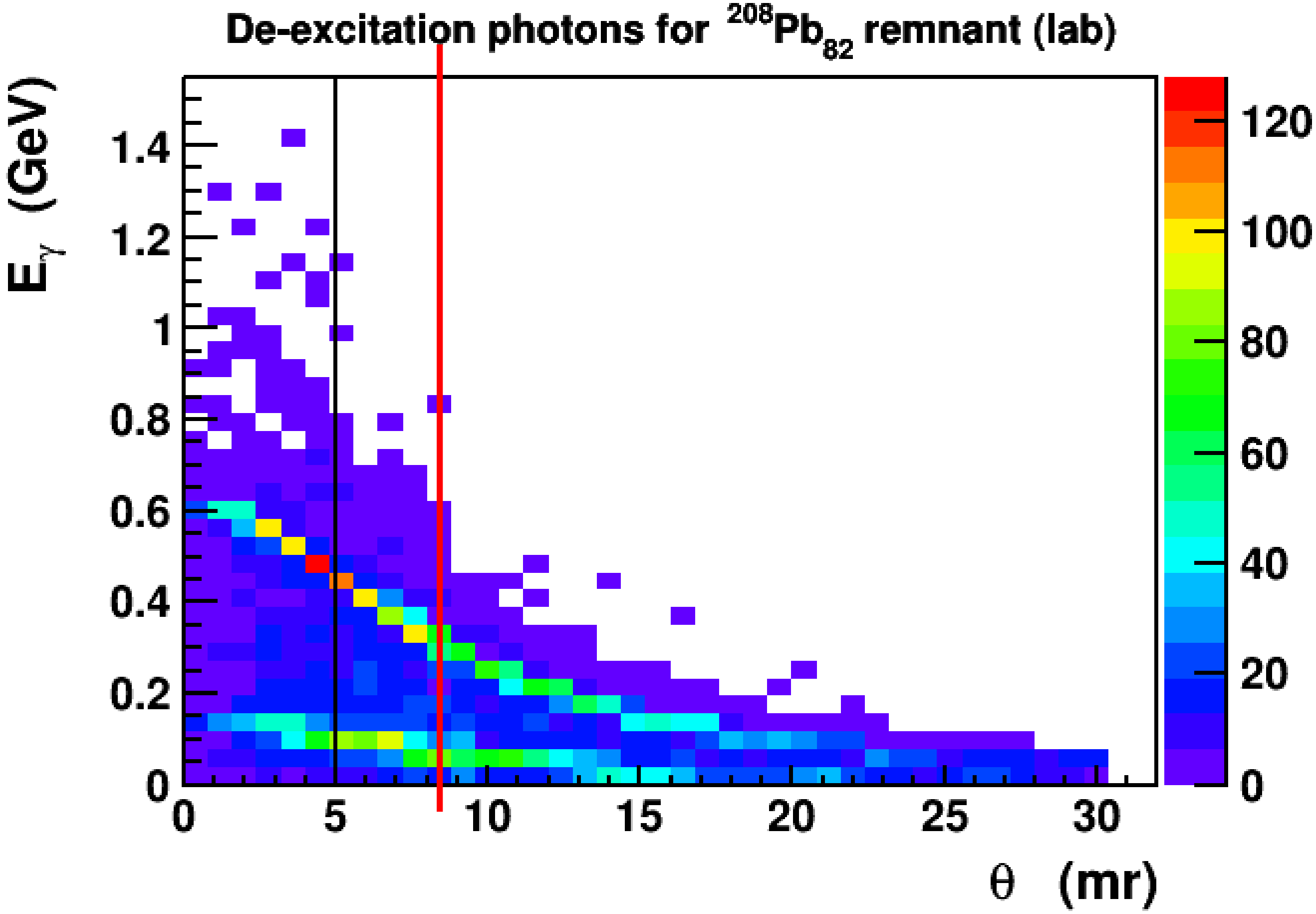
Photons from $^{208}Pb_{82}$ in lab frame



Detailed studies ongoing.

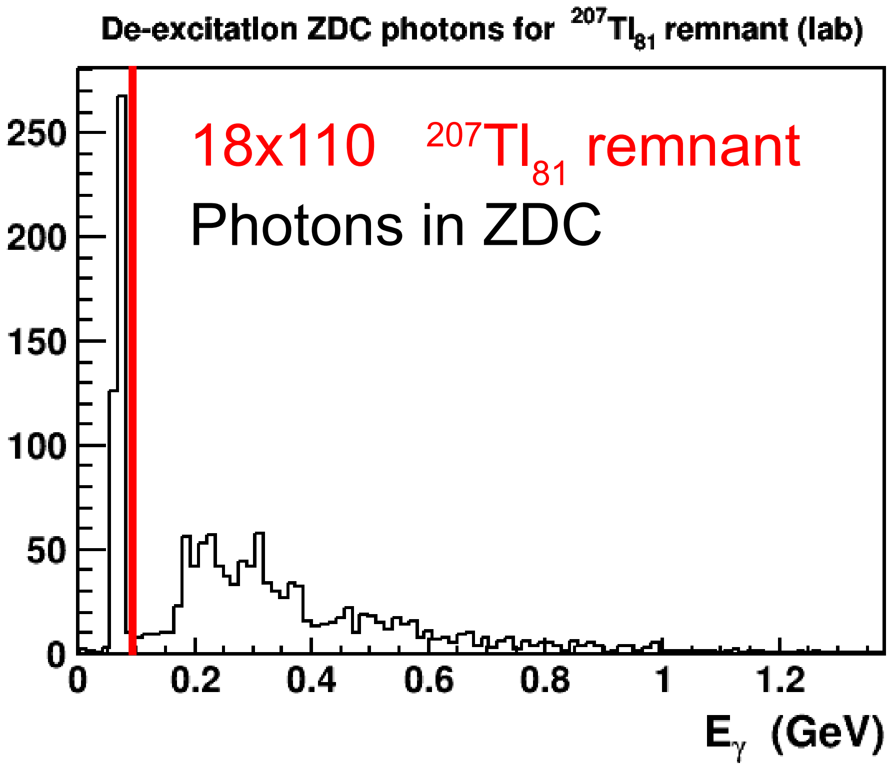
It is clear that γ's will be needed for low |t|!

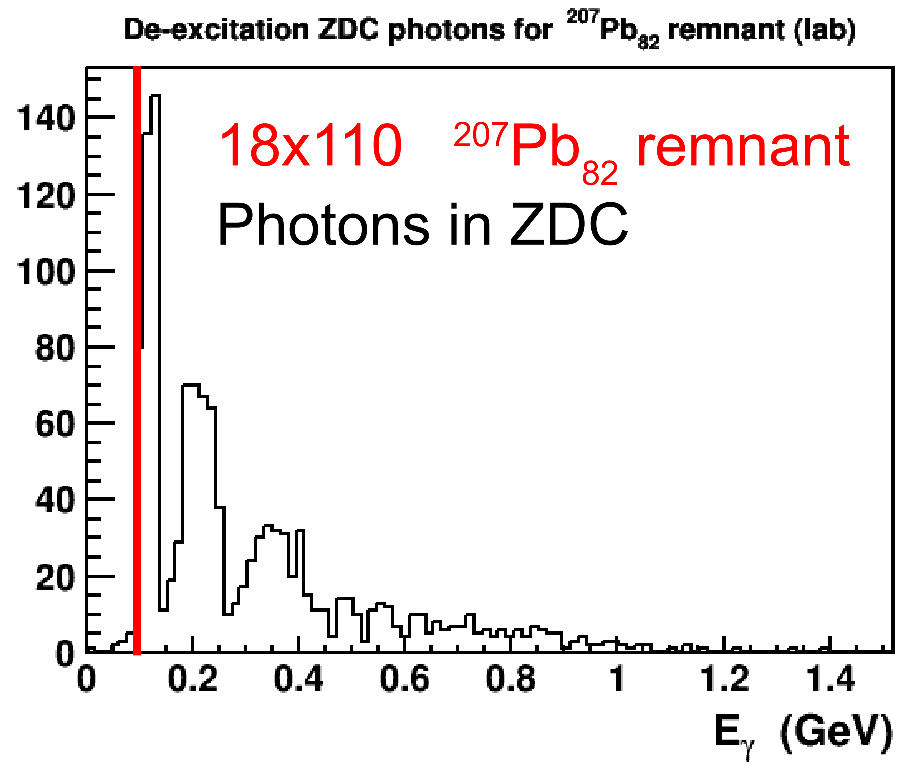
Bigger forward cone?



2-3 photons / per event. Half are in the forward TRF hemisphere:
$\theta<1/\gamma_{Pb}$ in lab or 8.5 mr for 18x110 (23 mr for 10x40). By momentum conservation: :
WE EXPECT AT LEAST ONE SUCH PHOTON PER EVENT!

Photons for high t?



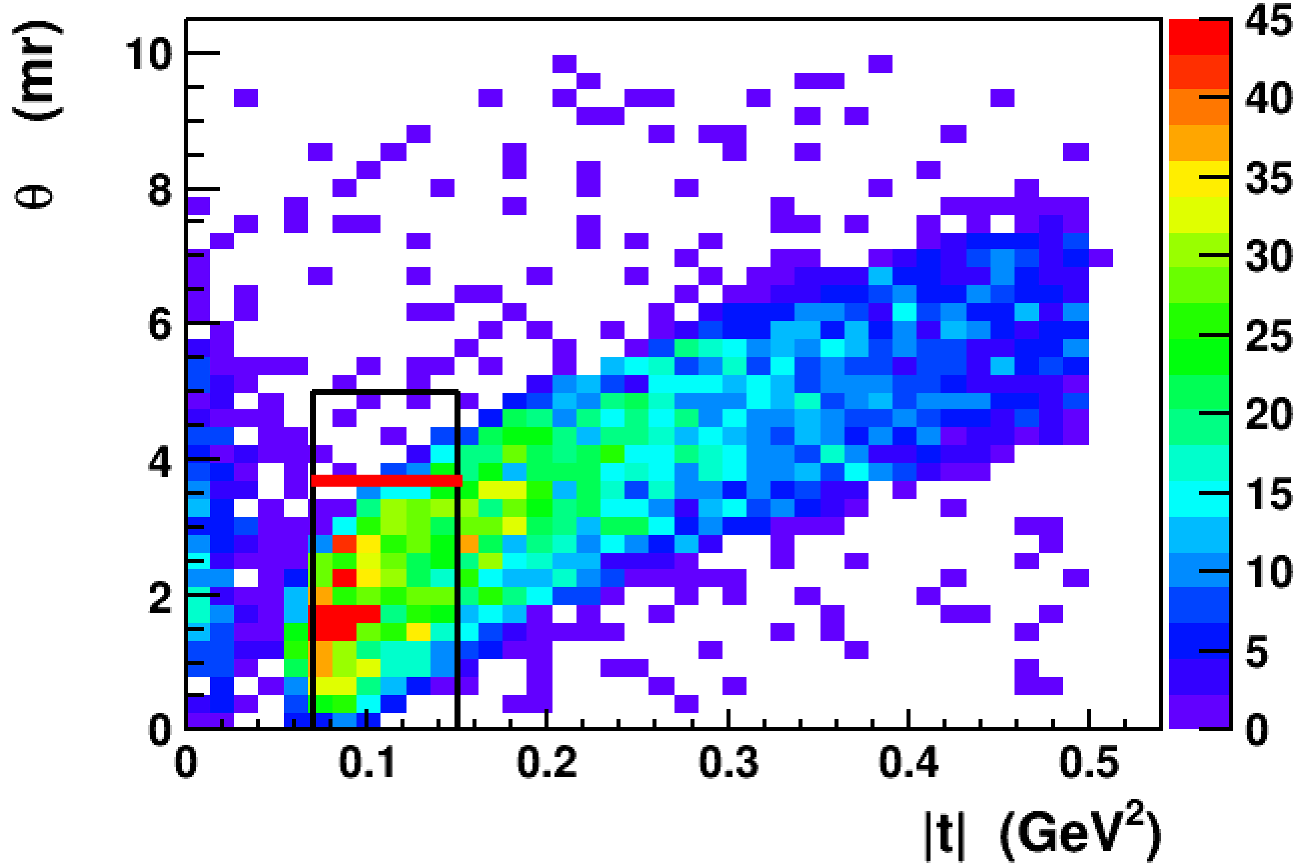


Around 50% of events have γ in ZDC for eRHIC.
Can help, but not good enough on their own.

How about n + $^{207}Pb_{82}$?

Neutrons detectable in ZDC for t range of interest !!

$^{207}Pb_{82}$ remnant. Knockout neutron (Nnevap=0). 18x110 p_F included

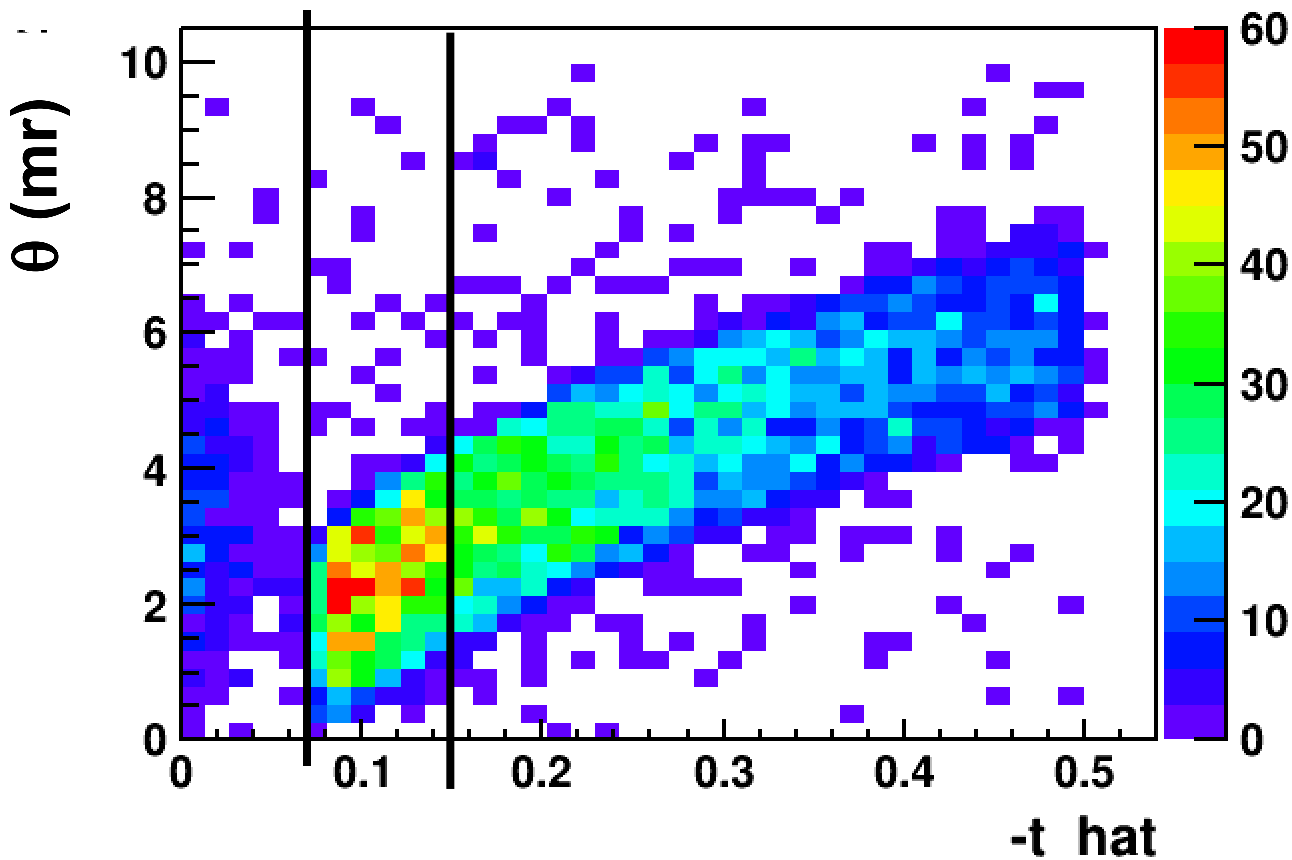


Black rectangle relevant to eRHIC ZDC

Red line is equivalent p_T for JLEIC ZDC 10mr x 40/110

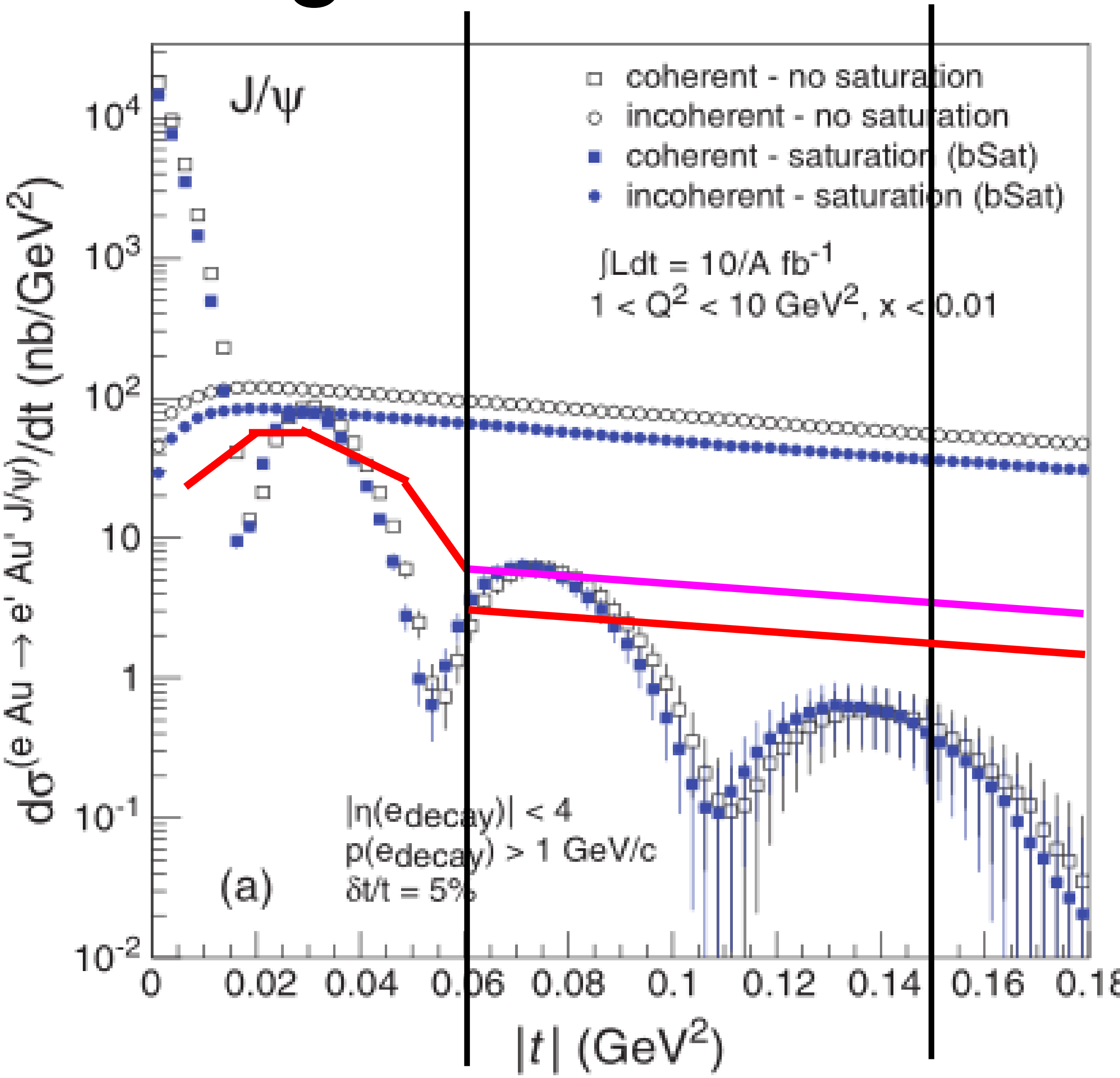
How about p + $^{207}Tl_{81}$?

18x110 p_F included



Need to accept all protons with <4.5mr at eRHIC, <12 mr at JLEIC OR the Thallium remnant (0.75% rigidity shift – difficult!).

ZDC n background veto inadequate



Incoherent (bSat) after:
Nnevap cut
ZDC neutron cut

Backgrounds with 0 evap. neutrons

- Low |t|: $\gamma^* + {}^{208}Pb_{82} \rightarrow \psi + {}^{208}Pb_{82} + \gamma + \gamma + \gamma ...$
  - Need to detect forward γ (in ZDC at least, ideally $\theta < 1/\gamma_{Pb}$ ~ 23 mr @ JLEIC). ~50-300 MeV scale
- $0.06 < |t| < 0.15$ GeV^2 : $\rightarrow \psi + {}^{207}Pb_{82} + n + \gamma + \gamma + \gamma ...$
  - Luckily, for $|t| < 0.15$ GeV^2, the ZDC catches the n!
- $0.06 < |t| < 0.15$ GeV^2 : $\rightarrow \psi + {}^{207}Tl_{81} + p + \gamma + \gamma + \gamma ...$
  - Must detect ${}^{207}Tl_{81}$ ($\Delta(Z/p)$ ~0.75% DIFFICULT!) or p ($\theta_{eRHIC} < 4.5$ mr $\theta_{JLEIC} < 12$ mr)

User interaction (1)

From the July 2015 EIC R&D Committee Report:

Recommendation: …
The committee encourages regular interaction between the developer[s] and the expected user community.

Mar. 2018: Baker talk at POETIC8 Satellite workshop: MCEGs for future ep and eA facilities (Regensberg, Germany) (eRD20: Aschenauer & Diefenthaler co-organizers)

Sept. 2018: Baker talk at Workshop on short-range correlations at an Electron-Ion Collider (CFNS BNL)

Note: Still planning for a PRD (Elke & Liang taking the lead).

User interaction (2)

Multiple groups (postdocs/students) are starting to use BeAGLE

Jefferson Lab

Morozov, Hyde, Turonski,+MDB+LZ et al. (G. Wei, M.Ehrhart) -
Geometry tagging and incoherent diffraction veto @ JLEIC.
Jet quenching for fixed target

Higinbotham, Hyde, Turonski,+MDB+LZ et al. (F. Hauenstein) –
Short-range correlations in e+A @ JLEIC

Furletova (A. Pilloni) - $e+D \rightarrow e' + J/\psi + n + p$ @ JLEIC

Maxwell – spin structure function rate calculations for JLEIC

Brookhaven

EA+MDB+LZ+Alexander Kiselev (W.Chang) Forward nucleons and photons from e+light-ion & $e+Pb \rightarrow e' + J/\psi + X$ @ eRHIC

Thomas Ullrich + Abhay Deshpande et al. (Z. Tu-Goldhaber fellow)
$e+D \rightarrow e' + J/\psi + n + p$ @ eRHIC

User interaction (3)

Detected a common theme in 4 of 6 projects!

Jefferson Lab

Short-range correlations in e+A @ JLEIC

$e+D \rightarrow e' + J/\psi + n + p$ @ JLEIC

Brookhaven

Forward nucleons from e+light-ion

$e+D \rightarrow e' + J/\psi + n + p$ @ eRHIC

All of these projects need a more realistic Fermi momentum distribution than that built into BeAGLE (from DPMJet3). Add that to ToDo list.

Progress & Plans Chart

Feature added or error corrected	12/17	06/18	07/18	Planned	
1-8. Early BeAGLE features (see text).	YES	YES	YES	YES	
9. Shadowing coherence length	NO	NO	NO	YES	
10. Partial shadowing effect	YES	YES	YES	YES	
11a. Effective σ_{dipole} for J/ψ averaged over x & Q^2	YES	YES	YES	YES	
11b. Effective σ_{dipole} for ϕ averaged over x & Q^2	YES	YES	YES	YES	
11c. Eff. $\sigma_{dipole}(x,Q^2)$ for $V=\psi,\phi,\rho,\omega$ from Sartre (ePb)	NO	NO	NO	YES	
11d. Use correct $R_{diff}^{(A=208)}(x,Q^2)$ for V from Sartre	NO	NO	NO	YES	
11e. Improved σ_{dipole} for V, if necessary	NO	NO	NO	YES	
12. Tune to E665 μA Streamer Chamber data	NO	NO	NO	YES	
13. FS p_F for hard process correct	Testing	Partial	YES	YES	Finally! Just in time...
14. Kinematic matching between DPMJet&Pythia	YES	YES	YES	YES	
15. Protect against very high E* values.	YES	YES	YES	YES	
16. Enable nPDF with any value of A,Z (EPS09)	YES	YES	YES	YES	
17. Extend R→ σ_{dipole} map to more values of A	NO	NO	YES	YES	Needed for μ+Xe
18. Tune the t distribution for multiple scattering.	NO	NO	NO	YES	
19a. Release α version BeAGLE/RAPGAP	NO	YES	YES	YES	Programs compatible.
19b-c. Install, test, & release BeAGLE/RAPGAP	NO	NO	NO	YES	} Key points for January
19d. Extend RAPGAP to include e+n (w/ H. Jung)	NO	NO	NO	YES	
20. Allow diffraction w/ individual $V=\psi,\phi,\rho,\omega$	NO	YES	YES	YES	ψ & ϕ are rare...
21. Cleanup and document BeAGLE work so far.	NO	NO	NO	YES	} New
22. Update Fermi momentum distributions.	NO	NO	NO	YES	
XX. Implement UltraPeripheral Photon Flux	NO	NO	NO	???	} Postpone
XX. Tune BeAGLE to UPC data (RHIC &/or LHC)	NO	NO	NO	???	

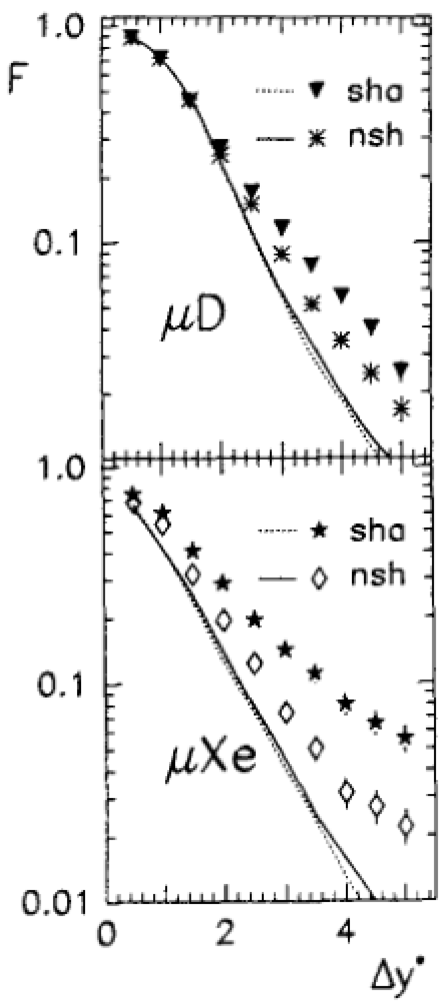
FY2019 plans

- Reduce uncertainty in BeAGLE detector design conclusions by better understanding our tune to FNAL E665 data using RAPGAP in BeAGLE.
  - Nuclear response weak at E665 → weak at EIC.
    - Encoded as long formation time (τ_0~5-7 fm/c) in produced particle rest frame for the intranuclear cascade .
  - Do we understand event mix @ E665?
    - Coherent & incoherent μ+A diffraction vs. DIS.
    - Incorporate RAPGAP (e+p diffraction) model in BeAGLE.
    - Tune to E665 μ+Xe event-by-event comprehensive streamer chamber data as well as μ+Pb/Ca neutrons.

The key issue

- From the white paper:
  - Coherent diffraction in eA is a "golden" channel.
  - But to realize it we'll need a good, and well understood detector (RejFac up to 1300!).
  - May be a key driver for forward detector/IR design.
- BeAGLE – with a better description of diffraction – is essential for properly evaluating the design of the forward detectors/Irs.
- So we need to include RAPGAP!

Incorporating RAPGAP



E665, ZPC 65 (1995) 225

Remaining integration tasks:

- Embed RAPGAP e+p into e+A (incl. Common block integration)
- Validate RAPGAP kinematic consistency

Upgrade RAPGAP to include e+n (w/ Hannes Jung)

- PDFs & Remnant (a la Pythia)
- Consistent kinematics

Hannes Jung, DESY

FY2019 milestones

- January 2019
  - BeAGLE cleanup
  - Full RAPGAP installation
  - Process-dependent e+A cross-sections
- May 2019
  - Compare BeAGLE to E665 Data
- September 2019
  - Tuning complete

FY2019 Budget Proposal

Person	Institution	Effort (FTE-year)	Cost to Proposal	Remarks
E. Aschenauer	BNL	0.05	$0	cost covered by BNL
M.D. Baker	MDBPADS[18]	0.25	$62,400	
J.H. Lee	BNL	0.05	$0	cost covered by BNL
L. Zheng	CUGW	0.10	$0	cost covered by CUGW
TOTAL:		0.45	$62,400	

Table 2: Personnel Budget Breakdown for FY2019

Item	Cost	
Personnel:	$62,400	= FY2018 + inflation
Zheng Travel	$4,500	NEW ITEM
Other Travel	$1,500	NEW ITEM
TOTAL:	$68,400	

Table 3: Total Budget Breakdown for FY2019

Impact of Reduced Budget

Funding Level	%Funding	Baker FTE	Travel	Project Completion
$68,400	100%	0.25 FTE	$6000 Liang+other	FY2019
$54,720	80%	0.20 FTE	$4500 Liang only	May extend into FY2020
$41,040	60%	0.16 FTE	$0 No travel	FY2020

Table 4: Impact of Reduced Funding in FY2019

- Forward Detector/IR design is advanced (pre-CDRs imminent).
- Many studies in progress at both laboratories.
- Need to understand how well these designs address critical e+A physics goals as well as any tradeoffs.
- A validated/tuned BeAGLE is quite urgent and should not be delayed.

External Support

- Salaries from home institutions:
  E. Aschenauer, J.H. Lee, L. Zheng
- JLAB LDRD: Geometry Tagging at JLEIC
  A. Accardi, MDB, R. Dupre, M. Erhart, C. Fogler,
  C. Hyde, V. Morozov (PI), P. Nadel-Turonski, K. Park,
  A. Sy, T. Toll, G. Wei, LZ
- Proposed JLAB LDRD: Short-range correlations in medium-to-heavy nuclei at JLEIC
  MDB, D. Higinbotham (PI), O. Hen, C. Hyde,
  V. Morozov , P. Nadel-Turonski, LZ

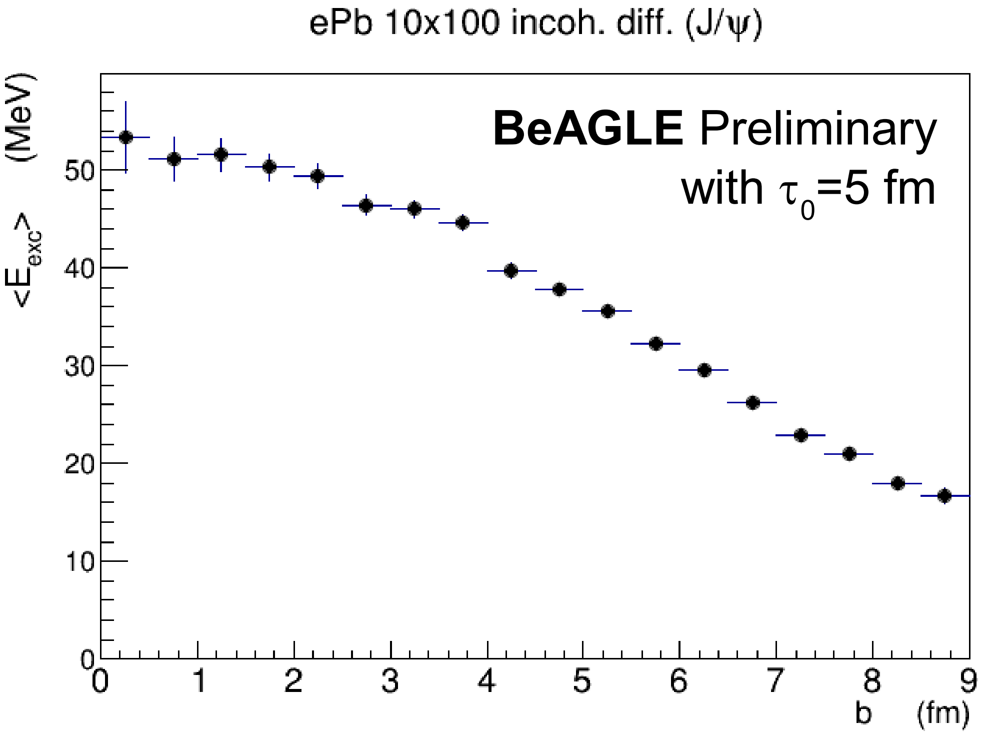
Conclusion

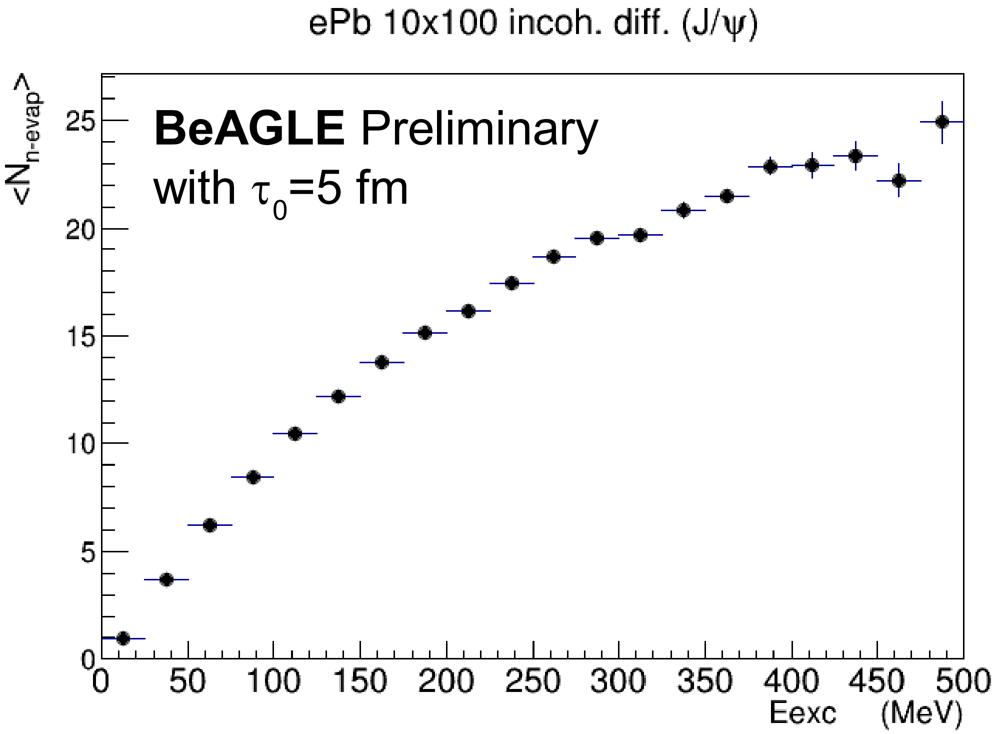
- ZDC alone (n+γ) probably NOT enough to tag coherent vs. incoherent diffraction.
  - Option 1: Forward protons (<4.5mr or 12mr)
  - Option 2: Detect Z-1 nuclei (0.75% rigidity change)
  - Option 3: Bigger cone for photons (8.5 or 23 mr)
- BeAGLE use/interest is taking off.
- Proposed upgrade & tune is urgent and timely
  - RAPGAP installation
  - Tune to E665 Streamer Chamber Data

Extras

The nucleus remembers!

Energy conservation!

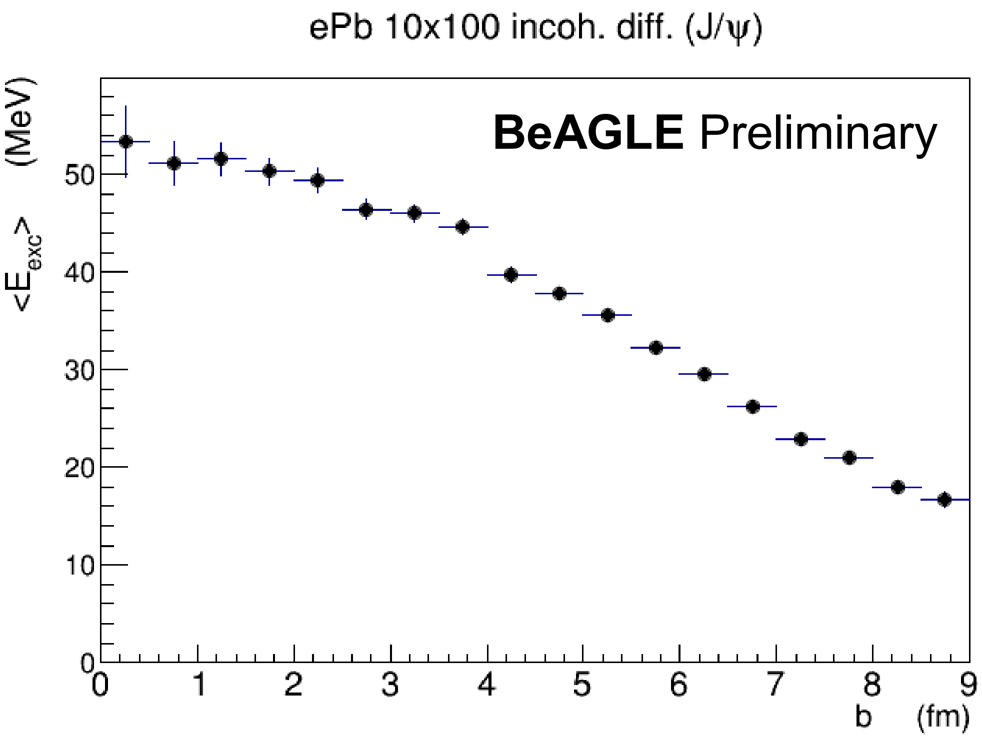


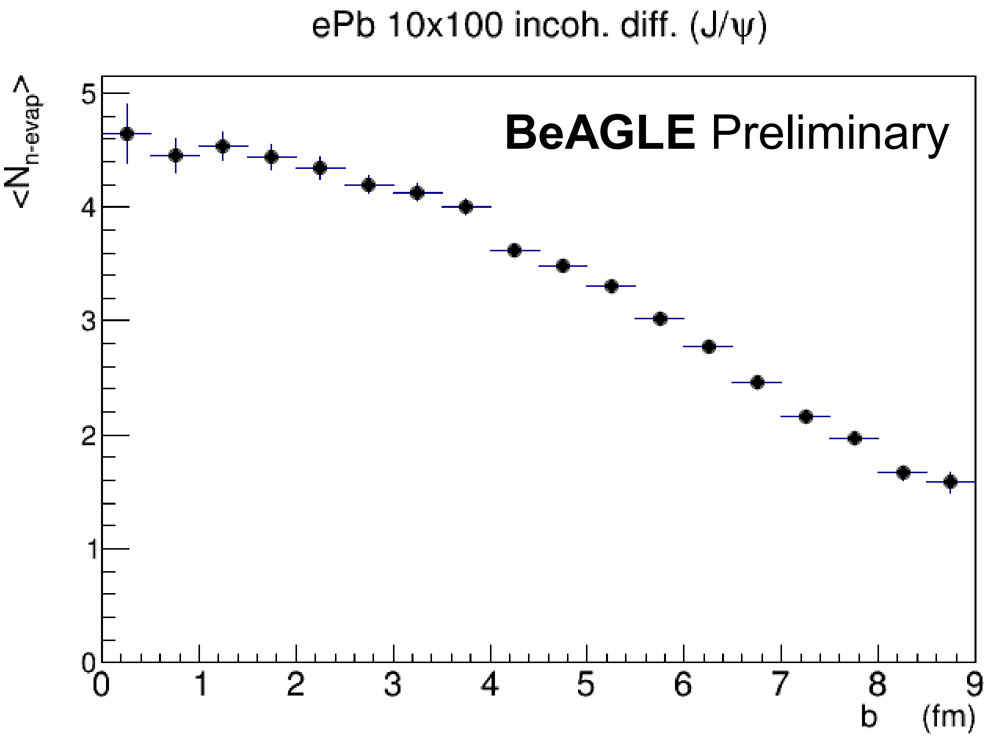


Central diffractive events excite the nucleus more than peripheral.

The hotter (more excited) remnant nuclei emit more evaporation neutrons – which we can detect!

ZDC & impact parameter correlated

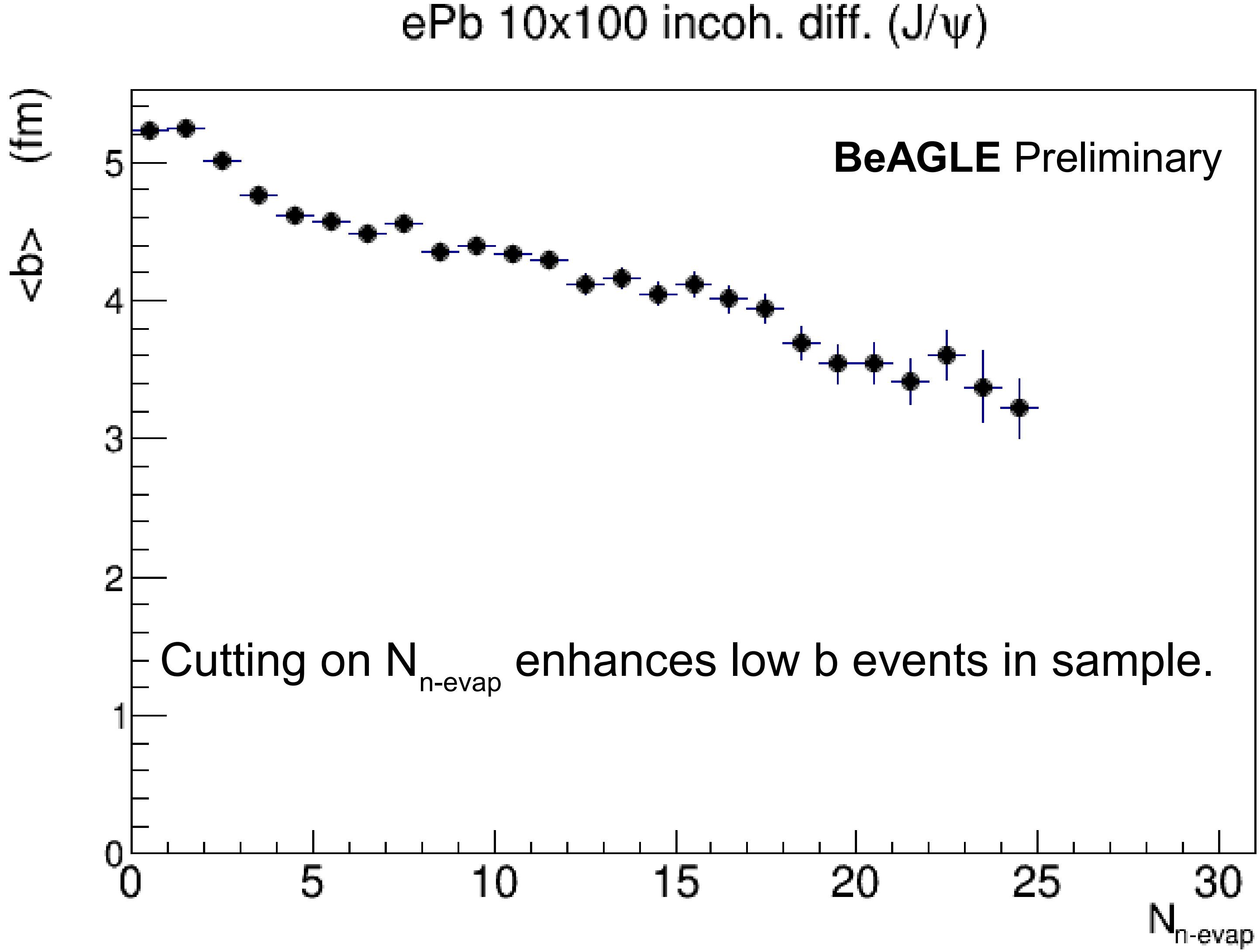




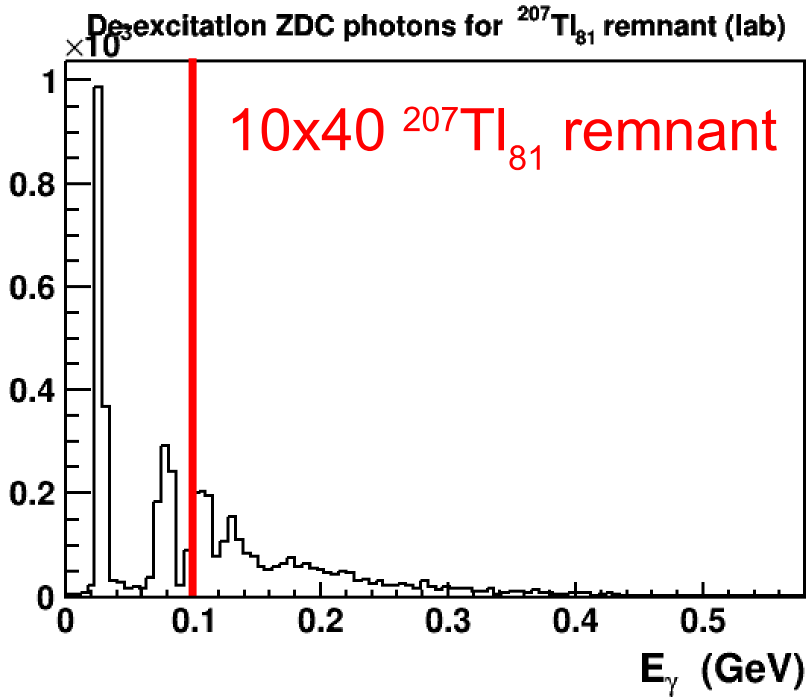
Central diffractive events excite the nucleus more than peripheral.

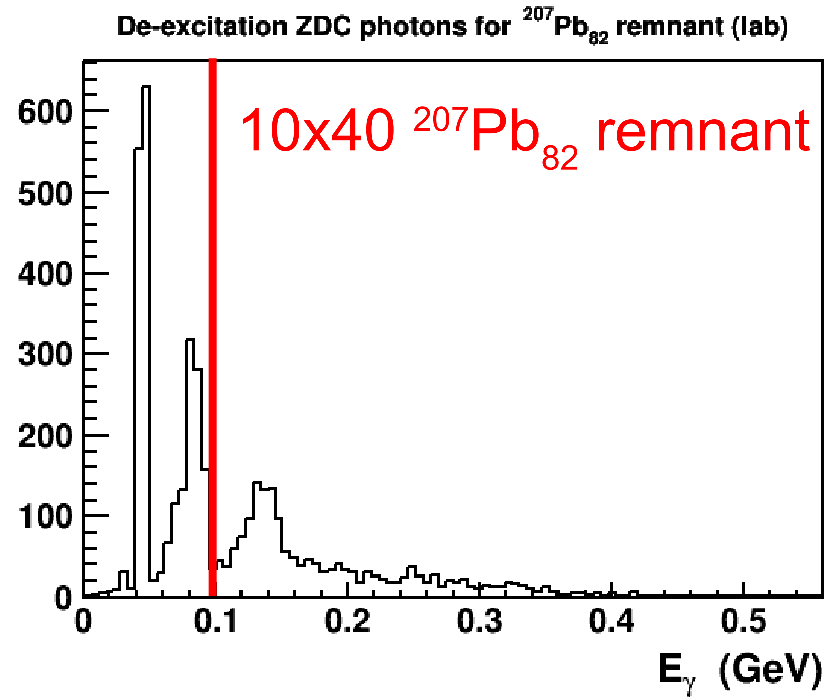
The hotter (more excited) remnant nuclei emit more evaporation neutrons – which we can detect!

ZDC can tag impact parameter!

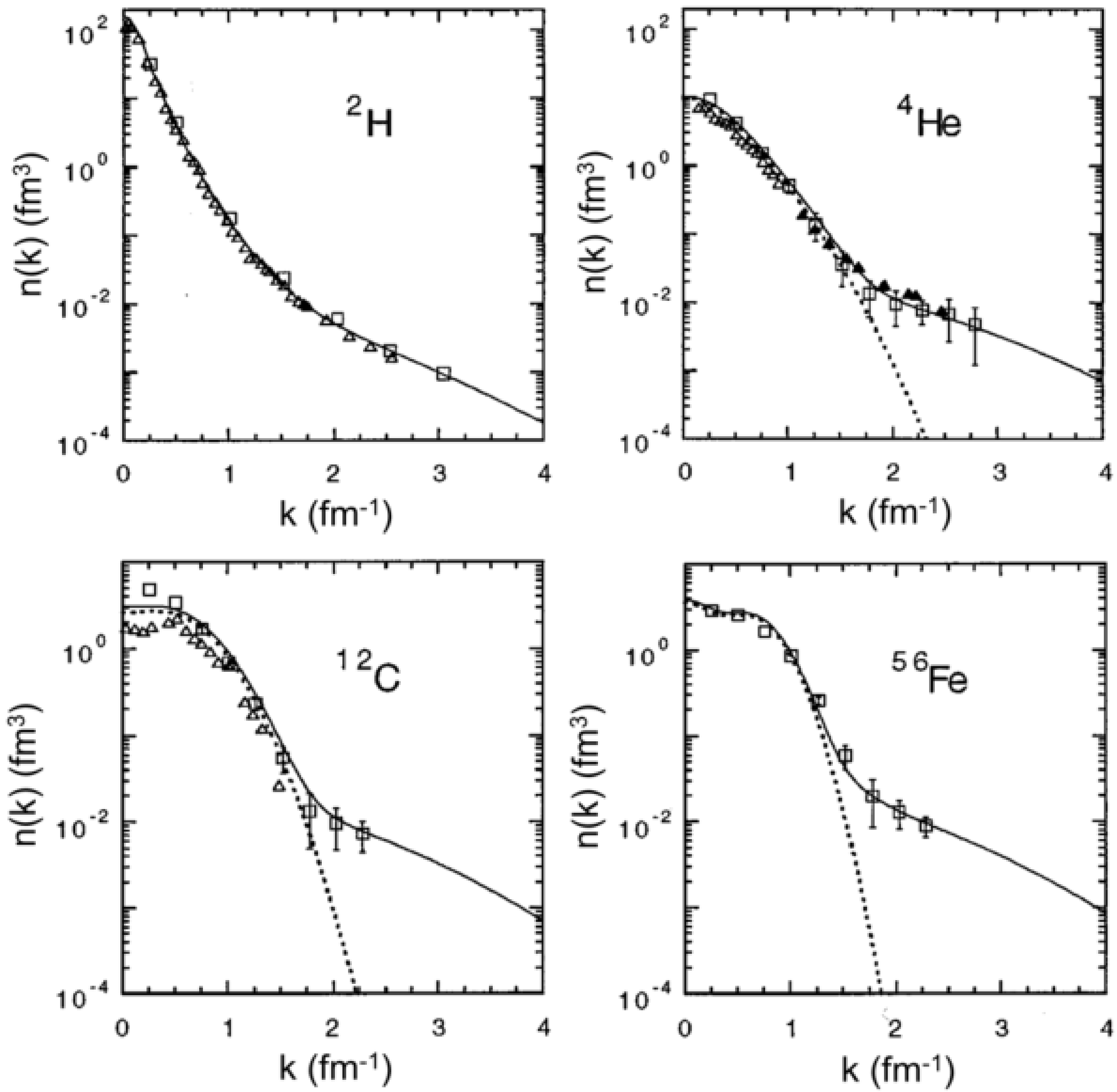


Photons for high t and lower s?





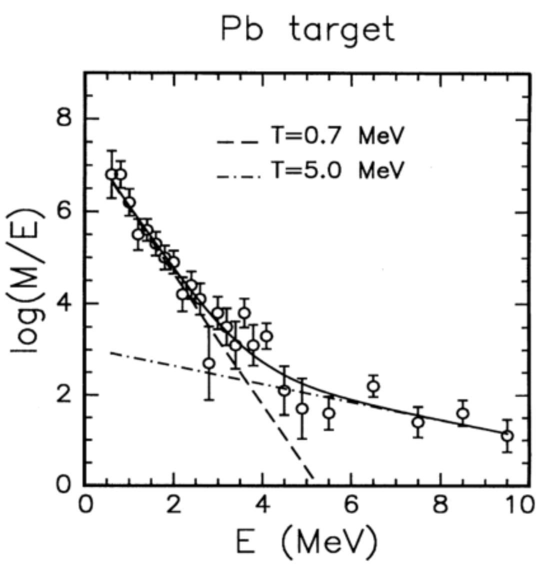
For A=207, 40 GeV/nucleon leads to fairly low energy photons.
Will add to the challenge at the lower energy.



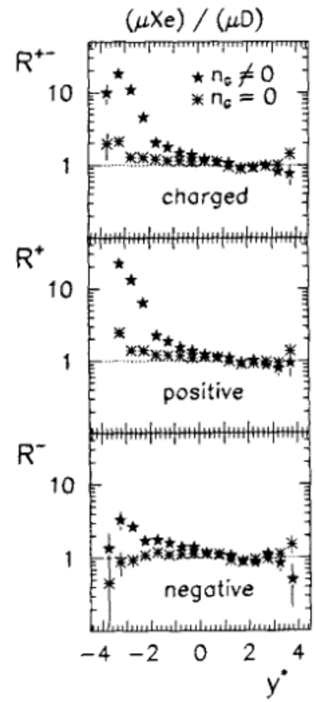
O. Hen, G.A.Miller, E. Piasetzky, L.B. Weinstein, Rev. Mod. Phys. 89 (2017) 045002

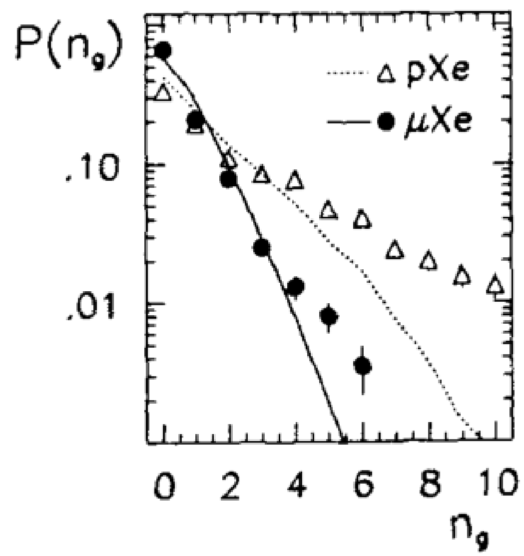
Some of the relevant E665 data

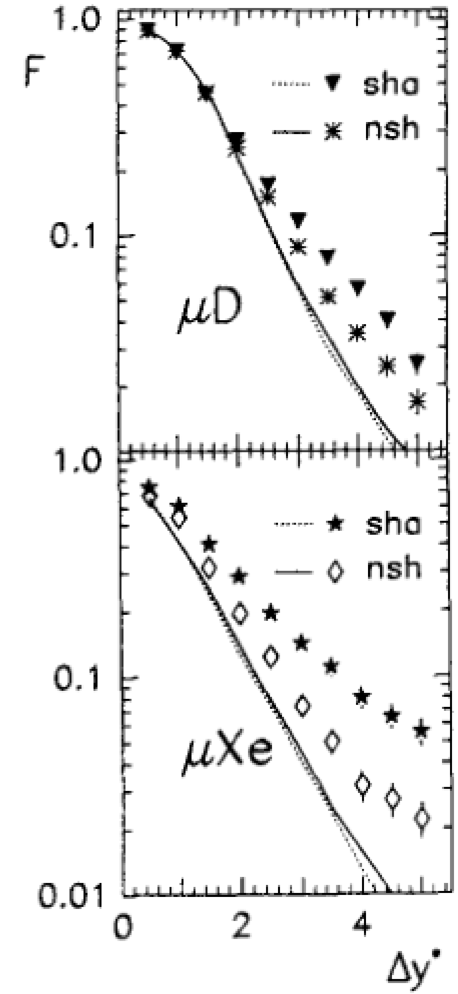
E665, PRL 74 (1995) 5198



E665, ZPC 65 (1995) 225







Fermi momentum & eN collision W^2

BeAGLE (& DPMJET & Pythia) use on-mass-shell nucleons which sit in a mean-field nuclear binding + Coulomb potential.

In nuclear target rest frame:

$Q^\mu = \{\nu; 0, 0, \mathrm{sqrt}(\nu^2+Q^2)\}$ defined by lepton – nuclear kinematics

$P^\mu = \{M; 0, 0, 0\}$ OR $\{M+E_{kF}; p_{xF}, p_{yF}, p_{zF}\}$

$W^2 = (P+Q)^2 = 2M\nu - Q^2 + M^2$ $(+2\nu E_{kF} - 2\mathrm{sqrt}(\nu^2+Q^2)p_{zF})$

High ν limit (ν>>M,Q):

$W^2 \sim 2M\nu\,(1 - p_{zF}/M)$ (note that $E_{kF} \ll p_{zF}$)

Math of Fermi momentum post-fix

In Pythia naive Hadronic CMS, we have:

invariant mass-squared W_0^2 & vector $\Sigma p = 0$

Want to expand it to correct $W^2_F = 2M\nu - Q^2 + M^2 + 2\nu E_{kF} - 2\mathrm{sqrt}(\nu^2+Q^2)p_{zF}$

Then boost the system with mass W_F to correct 3-momentum using $\beta_i = p_i/W_F$

Scale all hadronic 3-momenta by a common factor $\alpha=1+\delta$ to preserve vector $\Sigma p = 0$

$W_F = \Sigma_i \mathrm{sqrt}(\alpha^2 p_i^2 + m_i^2) \sim \Sigma_i \mathrm{sqrt}(E_i^2 + 2\delta p_i^2) \sim \Sigma_i (E_i + \delta p_i^2/E_i)$

$W_F - W_0 \sim \delta \Sigma_i p_i^2/E_i$ or $\delta \sim (W_F - W_0)/\Sigma_i(p_i^2/E_i)$

Scale momenta by $1+\delta$ and iterate (usually twice) until W_F is correct.

Note: For N=2, $p_1^2=p_2^2$ and we have an exact formula.